The Association
of
Engineering and Shipbuilding
Draughtsmen.

AN ELEMENTARY INTRODUCTION TO INDUSTRIAL ELECTRONICS.

By KENNETH J. FIELD, A.M.Inst. B.E.

Published by The Draughtsman Publishing Co., Ltd.,
96 St. George's Square, London, S.W.1.

SESSION 1945-46.

Printed by Milne, Tannahill & Methven, Ltd. (T.U.), 12-14 Mill Street, Perth

ADVICE TO INTENDING AUTHORS OF A.E.S.D. PRINTED PAMPHLETS.

Pamphlets submitted to the National Technical Sub-Committee for consideration with a view to publication in this series should not exceed 9,000 to 10,000 words and about 20 illustrations, making a pamphlet of about 40 to 48 pages. The aim should be the presentation of the subject clearly and concisely, avoiding digressions and redundance. Manuscripts are to be written in the third person.

Drawings for illustrations should be done either on a good plain white paper or tracing cloth, deep black Indian ink being used. For ordinary purposes they should be made about one-and-a-half times the intended finished size, and it should be arranged that wherever possible these shall not be greater than a single full page of the pamphlet, as folded pages are objectionable, although, upon occasion, unavoidable. Where drawings are made larger, involving a greater reduction, the lines should be made slightly heavier and the printing rather larger than normal, as the greater reduction tends to make the lines appear faint and the printing excessively small in the reproduction. In the case of charts or curves set out on squared paper, either all the squares should be inked in, or the chart or curve should be retraced and the requisite squares inked in. Figures should be as self-evident as possible. Data should be presented in graphical form. Extensive tabular matter, if unavoidable, should be made into appendices.

Authors of pamphlets are requested to adhere to the standard symbols of the British Standards Institution, where lists of such standard symbols have been issued, as in the case of the electrical and other industries, and also to the *British Standard Engineering Symbols and Abbreviations*, published by the B.S.I. in 1934 at 3/6. Attention might also be given to mathematical notation, where alternative methods exist, to ensure the minimum trouble in setting up by the printer.

The value of the pamphlet will be enhanced by stating where further information on the subject can be obtained. This should be given in the form of footnotes or a bibliography, including the name and initials of the author, title, publisher, and year of publication. When periodicals are referred to, volume and page also should be given. References should be checked carefully.

Manuscripts, in the first instance, should be submitted to the Editor, *The Draughtsman*, 96 St. George's Square, London, S.W.1.

For Pamphlets, a grant of £15 will be made to the Author, but special consideration will be given in the case of much larger pamphlets which may involve more than the usual amount of preparation.

The Draughtsman Publishing Co., Ltd., accepts no responsibility for the formulas or opinions expressed in its Technical Publications.

The Association
of
Engineering and Shipbuilding
Draughtsmen.

AN ELEMENTARY INTRODUCTION TO INDUSTRIAL ELECTRONICS.

By KENNETH J. FIELD, A.M.Inst. B.E.

Published by The Draughtsman Publishing Co., Ltd.,
96 St. George's Square, London, S.W.1.

SESSION 1945-46.

Printed by Milne, Tannahill & Methven, Ltd. (T.U.), 12-14 Mill Street, Perth,

CONTENTS

Page

Introduction - - - - - - - 3

Chapter I. Radio Heating - - - - 7

Chapter II., Electronic Control Methods - - 22

Chapter III. Photo Electric Cells - - - - 27

Chapter IV. Material Control - - - - 31

Chapter V. General - - - - - 36

Appendix I. Time Constant - - - 43

AN ELEMENTARY INTRODUCTION TO INDUSTRIAL ELECTRONICS.

INTRODUCTION.

THE industrial scope alone of electronic engineering is so wide and varied that several volumes could be written on any one aspect of it, and a pamphlet of this size will obviously not permit detailed exposition of any one example. Accordingly, an attempt has been made to provide the basic theory of various electronic apparatus, together with a rough outline of their particular industrial field, and once this theory has been properly understood, the myriad uses of electronics will become self-evident. For specialized study or reference an extensive bibliography is appended.

1. Electronics.

The term "electronics" or "electronic engineering" is properly used to indicate the science of the free electron, although in a loosely applied sense any apparatus using valves or other thermionic devices could be called "electronic."

2. The Electron.

The term "free electron" seems rather a peculiar one, in view of the fact that an electron is an integral part of atomic structure, and as such possesses a freedom of its own.

This freedom is only relative, as for example, in any ordinary piece of matter. Here the electron has movement, but only within its own atom, and further, this freedom is again restricted, the electron being compelled to rotate in a definite orbit around its parent nucleus. If the piece of matter selected is an electrical conductor, then the application of a voltage to its ends will cause any unattached electron to move along the conductor, its place being taken by an electron provided by the voltage source, and this "migration" of electrons constitutes an electric current. However, the electron even now is not "free," because it can only move inside the material, and cannot even exhibit a tendency to leave its conductor.

The whole of our conception of matter is based upon this elusive and infinitesimal particle, the electron, which is now generally regarded as an indivisible particle of negatively charged matter, having some characteristics akin to wave mechanics.

3. The Free Electron.

When the material of which the conductor is composed is placed in a vacuum or near vacuum and heated, then, provided sufficient heat is applied, a quantity of electrons will be liberated.

However, immediately these electrons leave their parent atom, that atom becomes a positive ion, and as such will attempt to capture any free electron that may be near. Thus, when the electrons have been released by heat they leave a positively charged body behind (Fig. 1), and as an electron has a negative charge, it is attracted back to this body. The net result is that a small cloud of electrons is formed around the positively charged conductor, and the only way to draw off these electrons is to place a further conductor having a much greater positive charge in close proximity to the emitter (Fig. 2). The cloud of electrons formed, as described above, is termed the space charge.

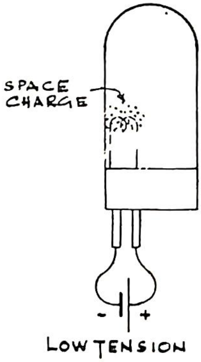


Fig. 1.

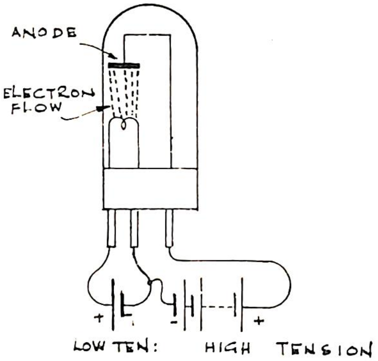


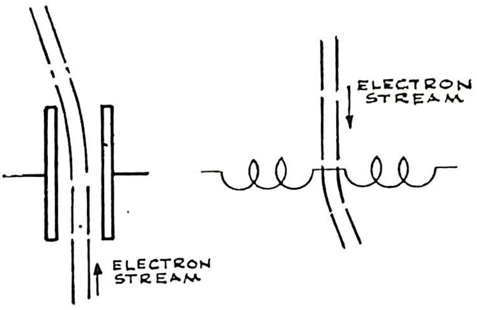
Fig. 2.

4. Control of the "Free" Electron.

The nature of electron flow is from minus to plus, and although flow is conventionally regarded as being from plus to minus, this is really incorrect. However, it is occasionally more convenient to regard current flow as being from positive to negative, and so most electronic engineers switch from "conventional" to "electronic" conceptions of flow, whichever seems more suitable at the time.

When once liberated, the electron can be used in an infinite variety of ways, and its control is very simple in substance. It can be controlled by external magnetic or electric fields (Fig. 3) and can be accelerated or retarded at will.

In addition to changes of course, and/or velocity, the electron stream can be focussed in the same manner as can a beam of light. Examples of electrostatic and electro-magnetic lenses are shown in Figs, 4, 5 and 6.



(a) Electrostatic Deflection. (b) Magnetic Deflection.

Fig. 3.

In Fig. 4, an ordinary "condensing" lens is shown. The function of the negative cylindrical shield is to bunch the electrons together and thus allow many more of them to be drawn through the circular gap at the centre of the anode. The chain dotted lines in the diagram indicate lines of force at equipotentials, and the dotted lines show the path of the electron stream as it condenses in passing through the "lens."

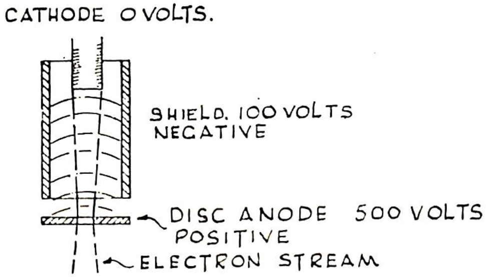


Fig. 4.—Electrostatic Lens.

A further lens system is the one shown in Fig. 5. Here, the two electrodes are again raised to different potentials, resulting

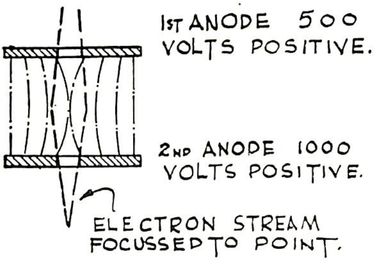

1ST ANODE 500 VOLTS POSITIVE.
2ND ANODE 1000 VOLTS POSITIVE.
ELECTRON STREAM FOCUSSED TO POINT.

Fig. 5.—Electrostatic Lens

in the creation of a curved flux line between them. The resultant path taken by the electron stream or "cathode-ray," as it is sometimes called, is that of a converging beam.

Only one example of the magnetic focussing methods need be shown, and this is the concentrating coil.

The cathode ray again cuts the curved flux produced by a symmetrical magnetic field, which bends the electron stream in on its centre. (Fig. 6).

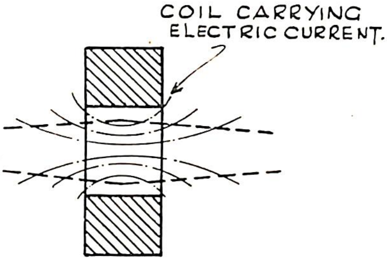


Fig. 6.—Electrostatic Lens.

The focal length of lenses of the electrostatic type is controlled by the voltage on the plates, while that of the magnetic lens is controlled by the current strength, *i.e.*, the density of the magnetic field.

5. Application of Electronics.

The industrial applications of the science of electronics can be broadly classified under four main headings :—

1. Processing.
2. Control apparatus and communications.
3. Safety devices.
4. Accurate measuring instruments.

Quite a large percentage of mechanical engineers seem to have an inherent distrust of thermionic valves and their associated apparatus, and to regard the use of electronic devices generally as being an unnecessary and complicating factor in any design job. It is most probable that this distrust arose in the days when the reception of a radio programme meant half-an-hour or more "fiddling" with a cat's-whisker and crystal, and radio sets were nothing but a mass of knobs and switches that had very problematical results on reception. It must be admitted that in those early days valves were often the weakest link in the radio chain, and a natural reluctance to give up old ideas may account for some of the prejudice existing to-day. However, when it is realised the extensive part played by all types of electronic equipment in our modern life, its reliability can no longer be in doubt. Valves are extensively used by the Post Office in trunk telephone services, and often this apparatus has to function for long periods without supervision. Some valve relays are used actually incorporated in a cable,* and the cable sunk to the ocean bed, so that reliability is almost the only factor to be considered.

Other aspects are. the extremely low breakdown percentage shown by B.B.C. transmitters, the utter reliance of modern commerce on high-speed, dependable communication services, and, in all, a host of services that are usually taken for granted.

Surely this is sufficient indication that electronic apparatus has passed from luxury to essential use.

CHAPTER I.

RADIO HEATING.

THERE are two types of radio heating, one known as "eddy current" heating, the other "dielectric" heating. As eddy current heating is the older of the two, it will be dealt with first.

1. Eddy Current Heating.

Every electric current has associated with it an electric and a magnetic field, and if the current is alternating (rapidly changing in value) then the magnetic and electric fields will also be alternating. It follows from this that alternating magnetic fields will induce alternating electric currents in any conductor they happen to traverse, and in fact this property of alternating fields is made use of in nearly all branches of electrical science to-day. Whilst a circuit may deliberately arrange to transfer energy in this way, *i.e.*, by electro-magnetic induction, it is obvious that all conductors placed in the alternating field, whether they form part of the circuit or not, will have currents induced in them. The currents induced in conductors other than those constituting the required circuit represent an energy loss, and are termed eddy currents. In radio heating, use is made of the "energy loss" due to eddy currents. A block diagram of the apparatus is given in Fig. 7.

In eddy current heating, the object to be heated is placed in the magnetic field created by a very heavy alternating current, and it has induced in it heavy eddy currents. The energy of these eddy currents is spent in overcoming the resistance of the material in which they are flowing, and is dissipated as heat. The dissipation of heat through the substance will naturally cause a rise in temperature, and the more energy that can be dissipated in this way, the higher the final temperature will be—within certain limits.

The higher the frequency used in generating these alternating magnetic fields, the greater the tendency for the induced or eddy currents to concentrate near the surface of the conductor, until at very high frequencies these eddy currents do not penetrate more than $\frac{1}{16}''$ or so into the material being heated. This property of high frequency currents, known as the skin effect, is made use of in the case-hardening of small tools, crankshaft bearings, gear wheels, and in fact anything requiring a hard case on a tough core.

---

* G.P.O. 48-circuit telephone cable beneath the Irish Sea.

As is well known, the usual method of case-hardening is the heating of the whole article in the presence of chemical compounds which change the composition of its surface metal, cooling, reheating and quenching. This involves a whole series of processes, each taking considerable time, each involving a considerable amount of energy and handling—all expensive factors in modern production methods. In addition, there is the possibility of non-uniform depth of case, surface cracking, and distortion during cooling. With eddy current heating at high frequencies—usually termed radio-frequency heating—the whole process is completed in a matter of seconds, and since the body of metal remains cold, it is self-quenching, provided the volume of unheated metal is large in comparison to the heated volume. An actual time for the hardening of a 3·5″ outside diameter worm and shaft, was 4·5 seconds.

Should the relation of unheated to heated volumes be too small to permit of sufficiently rapid self-cooling, then the article can be heated whilst under water. The steam jacket formed around the heated body is sufficiently insulating to allow full hardening temperature to be reached, and when power is cut off the surrounding water immediately quenches the metal.

2. Eddy Current Heating Applications.

Low frequency eddy current heating has been in use for several years in the melting of special steels and alloys, for heating valve electrodes during the air exhaustion process, and for the "running" of tin plate that has been electro-deposited. Depositing tin plate on various metals by the electro-plating method has long superseded the expensive "hot-dipping" system, but electro-deposited tin is porous with a dull grey colour, and can only be made glossy by

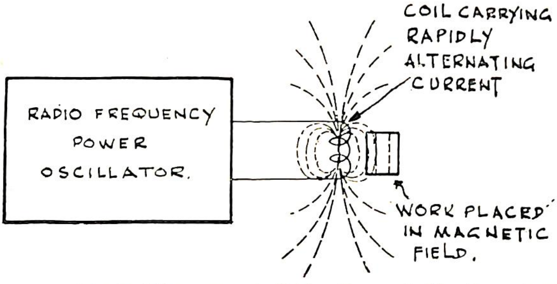

RADIO FREQUENCY POWER OSCILLATOR.
COIL CARRYING RAPIDLY ALTERNATING CURRENT
WORK PLACED IN MAGNETIC FIELD.

Fig. 7.—Block Diagram of Eddy Current Heating Apparatus.

re-melting, or "re-flowing," as it is called. The use of eddy current heating enables this re-flowing to be done continuously and efficiently.

It may be of interest to quote here a formula derived by Babat & Losinsky,* and giving the thickness in which 90% of the heat is generated in E.C.H. (eddy current heating)

$$t = \frac{1}{2\pi}\sqrt{\frac{\rho}{\mu f}}$$

where t = thickness in centimetres.
μ = permeability of the material.
f = frequency in cycles per second.
ρ = specific resistance of the material in ohms per centimetre cube $\times 10^9$ (C.G.S. units).

For carbon steel at 20°C. this becomes

$$t = \frac{20}{\sqrt{f}} \text{ millimetres.}$$

The power dissipated in eddy current heating of materials is proportional to the specific resistance and permeability in the manner

$$\text{Power} \propto \sqrt{\mu\,\rho}.$$

It will be seen that a material with low specific resistance and permeability will be extremely wasteful in E.C.H., and this is borne out by the fact that the heating of brass, copper, and other non-magnetic, mainly good conducting materials, by the eddy current method is rarely justified industrially. An interesting application of the fluctuating magnetic field produced by a R.F. heater is in the casting of some metals, notably light alloys. The mould is subjected to a strong uni-directional magnetic field, and also to the varying field produced by the oscillator. This produces varying electrostatic and electromagnetic stresses in the material, the resulting molecular interaction giving a better grained and blow free casting.

3. Dielectric Heating.

In order to understand the principle employed in dielectric heating it will be necessary to study the working of a condenser in some detail.

The term "condenser" is an unfortunate one, and an electrical condenser in no way "condenses" electricity, it merely stores it. In its simplest possible form a condenser consists of two parallel metal plates separated by a plate of insulating material (Fig. 8), such as glass, mica, paper, etc.

---

* "Journal I.E.E." Vol. 86, February, 1940.

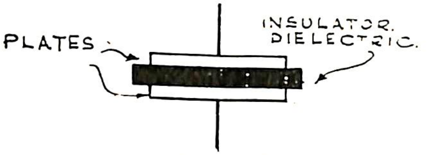


Fig. 8.—Simple Condenser.

This insulating material is called the "dielectric," and it serves to prevent the passage of electrons from one plate to the other, and, in effect, it therefore prevents current flow. Now, assume an electric battery be connected to the condenser in Fig. 8, producing the conditions shown in Fig. 9

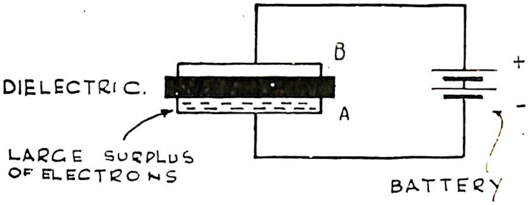


Fig. 9.—Charged Condenser.

What happens is this. When an electromotive force, or voltage, is applied to the condenser, electrons flow on to the negative plate—negative because it is connected to the negative terminal of the battery—and their strong negative electric field repels the electrons in the dielectric. Because the dielectric is a good quality insulator its electrons do not become free, but move ever so slightly away from the negative field, and thus a state of strain exists in the dielectric. In moving away from the negative field on the one plate A, the electrons in the dielectric must obviously approach the plate B, and so repel the electrons in that plate. As B is a good conductor these electrons become detached and flow into the positive terminal of the battery, which, it will be remembered (page 4) is deficient in electrons. This makes plate B positive in sign. If the battery be removed, the condenser will still remain charged, because there is no path to enable the surplus electrons on the negative plate to make good the deficiency existing on the positive one.

It will be seen that during the charging operation a current flows round the circuit, and only when the condenser is fully charged will the dielectric act as a break in the circuit. If A.C. is applied to a condenser, then, because alternating current is constantly changing in polarity, that is, from zero volts to plus maximum down through zero again to minus maximum, (Fig. 10) the condenser to which this alternating voltage is applied, will be constantly charged up, discharged, charged up in the opposite direction, and so on continuously. Thus, in effect, current will continue to flow through the circuit, and the dielectric of the condenser will not act as a bar. The higher the frequency, or the more rapidly the voltage changes polarity, the more current flowing through the circuit—in other words—the bigger the movement of electrons in a given time.

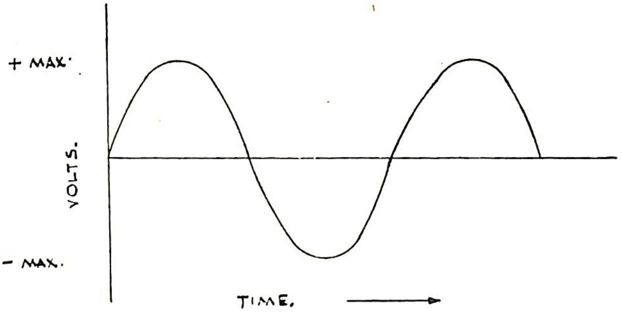


Fig. 10.—Alternating Current.

Of the total energy used in moving the electrons in the dielectric, the majority is given back when the condenser is discharged, that is, when the dielectric electrons return to their normal position, but some of the energy is lost due to this moving about. It is this loss of energy, called the dielectric loss, that is used in dielectric heating. The part of the lost energy that is dissipated as heat raises the temperature of the dielectric, and so in this type of radio heating the material to be heated is placed between the plates of a simple condenser, *i.e.*, it is used as the dielectric, and the frequency and amplitude (voltage) of the applied A.C. will control the amount of dielectric loss which is the temperature rise.

4. Dielectric Heating—Applications.

This system of heating insulators, by virtue of their power factor as a dielectric, is used extensively in the plastics and plywood industries. It is especially valuable where multi-ply woods are to be heated and glued, because the heat supplied by this dielectric method is applied evenly throughout the whole block, and thus obviates the long time lag experienced with the more usual methods which entailed waiting for the heat to penetrate through the poorly conducting wood to the internal glue layers.

Piles of plywood sheets bonded with waterproof thermosetting resins are "cured" while under pressure by using the top and bottom platens of the press as *one* plate of the condenser, and using a thin metal sheet placed in the middle of the pile as the other plate. The platens of the press are connected to earth, thus making for greater operational safety, and the high frequency voltage applied between centre sheet and earth.

Dielectric heaters of very high powers—up to 400 kilowatts—have been constructed for plywood heating, and the areas and thicknesses concerned are unlimited, provided sufficient R.F. power is available.

Dielectric heating may also be said to be an accepted part of the plastics industry, where large block mouldings are pre-heated by this method before transfer to the hot press. This enables thicker mouldings to be produced than is the case with usual heating methods, because normally, with a thick moulding, the outside is cured before the inside. This is the reason why most bakelite mouldings on the market are of shell-like form, and why dielectric heating, with its assurance of better heat distribution, enables bigger and faster mouldings to be produced.

The final stage of food dehydration, or "drying" as it is sometimes called, is in several instances accomplished by the dielectric process, and very high powers are used in this application.

Dielectric heating with the "spot welding" technique is used extensively in America for sealing cellophane packages of all kinds, and in this country spot dielectric heating with R.F. power has been developed for tacking the edges of plywood sheets used in the aircraft industry.

Mention may be made here of the many surgical and medicinal uses of high frequency electrical currents, both in electro-surgery and dia-thermy.

In electro-surgery, the use of high frequency, high-voltage currents enables bloodless incisions to be made, whilst the application of dielectric heating means that deep-seated tissues or organs can be heated selectively. The heating of body tissues was one of the first applications of radio heating.

In view of the increasing importance to industry of radio-frequency heating, oscillator design is dealt with rather fully in the following sections.

5. Design of Radio-Frequency Heating Equipment.

The Oscillator. (Eddy Current Heating).

In the design of oscillators for industrial heating purposes the main considerations are that power from the mains at the standard frequency of 50 cycles/sec. shall be converted efficiently into power at frequencies as high as 50 million cycles/sec., and that the equipment used shall require the minimum amount of maintenance.

There are two main types of circuit that could be used :—

1. Master-oscillator and amplifier.
2. Self-excited oscillator.

Choice will generally fall on the self-excited oscillator for the following reasons.

In equipment using a master-oscillator, the actual power stage is separated from the stage controlling the frequency of the output energy, and thus when the "work," as the material being heated is usually called, is placed in the heating coil, the frequency of the output stage can change without affecting the frequency being generated by the master-oscillator. This means that the two circuits get out of step immediately, with a consequent disastrous power loss.

In the self-excited power oscillator the insertion of the "work" in the heating coil will still cause a change of frequency, but the oscillator will be self-adjusting to this change, and so efficiency will remain reasonably constant. It is possible for this change in frequency to amount to as much as 25%.

Because such large outputs are required, coupled with economy in the use of valves, the choice of operating conditions for the circuit is automatic, falling under the heading of class "C." In class "C" operation the valve is supplied with power only during a part of half a cycle, the inductance and capacity of the circuit being relied upon to supply the required energy for the rest of the cycle. This is analogous to the action of a flywheel in mechanical engineering.

A class "C" operated valve is biased to twice cut off, *i.e.*, to twice the value necessary to prevent anode current flowing in spite of the voltage existing on the anode. Large R.F. voltages are then imposed on the grid during part of each cycle, driving it positive and thus causing maximum anode current to flow. It will be seen that at maximum positive grid voltage anode current will be maximum and anode voltage minimum.

Minimum anode voltage occurs because the current flowing through the output coil (called the "tank" coil) will be at maximum and therefore a considerable amount of the available voltage will be dropped across this coil.

At this moment of maximum grid voltage and maximum anode current, the A.C. resistance of the valve will be at its minimum value, and therefore the voltage drop across the valve will be at its lowest figure.

Thus, with a low volt drop across the valve and a high volt drop across the tank coil, plate efficiency will be at its highest and maximum power will be available for heating the work.

To obtain high power outputs without the necessity for over-running valves, and to overcome the possibility of poor load factors, use is commonly made of two valves operated in "push-pull."

In this arrangement the valves operate alternately, each valve supplying power for part of one-half cycle in turn. The tank circuit does not now have to provide power during a whole half cycle, but only during part of each half cycle.

Using the average quality class "C" valves in push-pull, a power efficiency of 60% can be regularly achieved and quite frequently exceeded.

6. Oscillator Design.

Fig. 11 gives the fundamental circuit diagram of an average self-excited push-pull power oscillator.

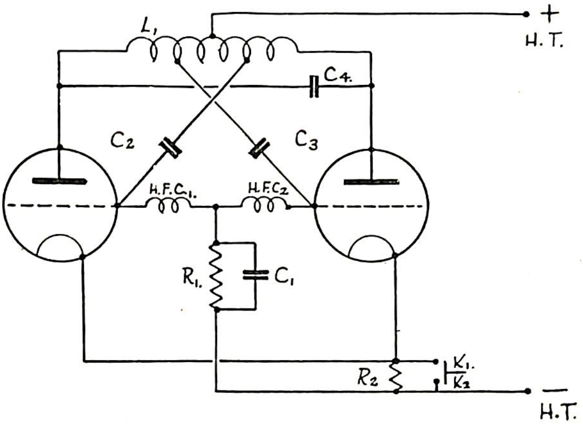


Fig. 11.—Component values are discussed in text.

COMPONENTS.

(*a*) HFC$_1$ HFC$_2$ (CHOKES).

In this circuit, high frequency chokes HFC$_1$ and HFC$_2$ are used to prevent the radio-frequency drive voltages applied to the grid from being short circuited to earth by way of grid leak and condenser network $R_1 - C_1$.

(*b*) R_1 (GRID LEAK).

The value of R_1 is simply calculated from Ohm's law,

$$R = E/I$$

where E is the value of grid bias required and I the peak R.F. grid current. Peak R.F. current flowing in the grid circuit under class "C" conditions is about 30% of the D.C. anode current, D.C. grid current about 15%. Table I. shows D.C. anode current and R.F. anode current expressed as a percentage of the total permissible current flow. This total current flow should be taken as lying between 80% - 95% of the total filament emission.

The part of the half cycle of 180° during which the grid is driven positive will obviously depend upon both the value of biasing

TABLE I.

Relation of Direct and Alternating Components of anode Current to Total Emission Angle of Flow.

ANGLE OF FLOW IN DEGREES.	D.C. ANODE CURRENT. Per Cent.	A.C. ANODE CURRENT. Per Cent.
120	19·5%	35%
125	20%	36%
130	20·8%	37%
135	21·5%	38%
140	22%	39%
145	22·8%	40%
150	23·5%	41%
155	24·1%	42%

voltage chosen and the value of drive voltage applied, and should the bias voltage be fixed at cut-off point, then obviously any positive drive voltage applied will commence to push the grid positive. This would mean that grid current would be flowing for 180° of the complete cycle, and the arc of operation or "angle of flow" would be said to be 180°.

It has been shown (Section 5) that when the grid voltage is at positive maximum ($E_{g\,max}$) anode voltage is at minimum ($E_{a\,min}$). Then under those conditions maximum energy would be delivered to the work because the anode efficiency would be very high, *i.e.*, very little energy would be dissipated inside the valve as heat. From this it will be seen that if the length of time taken for the grid to reach $E_{g\,max}$ can be shortened, then the anode efficiency will be correspondingly higher, and the length of arc during which the grid is positive will be shortened, *i.e.*, its arc of operation will be reduced. There is (as usual) a snag in this. As the grid pulse is shortened, the anode efficiency will be higher, but the valve will be supplying current for a much shorter period, and this means that energy will be subtracted from the tank coil in order to maintain the oscillation. The overall efficiency, called the "power efficiency," will therefore be lower.

In practice, it is usual to take an angle of flow of about 140°, which will give a reasonable compromise between anode and power efficiencies.

The value of bias voltage required to give an angle of flow of 140° can be found from the formula :—

$$E_{gb} = \frac{E_{ht}}{\mu} + \left(E_{g\,max} + \frac{E_{a\,min}}{\mu}\right) K \qquad (1)$$

where E_{gb} = Bias voltage.
E_{ht} = High tension voltage (anode voltage).
$E_{g\,max}$ = Maximum positive swing of grid.
$E_{a\,min}$ = Minimum anode voltage.
μ = Amplification factor.
K = ·51941 for 140° angle of flow.

K can be found for other angles from the equation :

$$K = \frac{\cos(\theta/2)}{\text{vers}\,(\theta/2)}$$

The maximum voltage reached by the grid ($E_{g\,max}$) must under no circumstances exceed minimum anode voltage ($E_{a\,min}$), because if it did so an inordinately high grid current would flow with detrimental results to the valve.

The figures for grid current can be obtained from characteristic curves supplied by the valve manufacturers, as can the figure giving maximum total emission of the valve, which will naturally be the sum of maximum grid and anode currents. When this total emission figure is obtained, $E_{g\,max}$ and $E_{a\,min}$ should be chosen, so that the total current flow at these figures is 80% - 95% of the maximum flow possible, and the difference between $E_{g\,max}$ and $E_{a\,min}$ must lie between 3% - 7% of the high tension voltage of the valve, E_{ht}.

(*c*) C_1 GRID CONDENSER.

The value of grid condenser C_1 will depend largely upon the frequency on which the valve is required to operate and the value of R_1, since C_1 must not be small enough to discharge appreciably during one cycle, nor yet large enough to absorb sufficient energy to cause self-quenching, *i.e.*, intermittent oscillation. A fairly safe value is one chosen, so that :—

$$C_1 = 10^7/fR_1 \qquad (2)$$

where C_1 = grid condenser capacity, in micro-Farads.
f = frequency in cycles/sec.
R_1 = grid resistance in ohms.

Alternatively C_1 may be made so that its reactance at the operating frequency is between 2% - 5% of the resistance of R_1.

(*d*) R_2 SAFETY BIAS RESISTOR.

R_2 is a cathode resistor inserted for protection should the valve fail to oscillate. Contacts K_1 and K_2 are normally held closed by a relay in the anode circuit so that R_2 has no effect on operating conditions. Should the valve fail to oscillate, then the standing anode current would rise to a very high value, operate the relay, and automatic bias would be applied, bringing the anode current to a safe value. The relay is not self-resetting, so that the cycle of events cannot recur until any circuit fault has been corrected and the relay set by hand. The value of R_2 is obtained from valve characteristic curves.

(*e*) C_2 . C_3 . FEEDBACK CONDENSERS.

The capacity of condensers C_2 . C_3 . is not very critical. The main point to be observed is that their reactance at operating frequency shall be extremely low in comparison to the inductive reactance of the chokes HFC_1 HFC_2 at that frequency.

This is to ensure that the R.F. voltage supplied from the tank circuit shall be developed between grid and earth and not distributed between grid, earth and across condensers C_2 : C_3.

(*f*) L_1 . TANK COIL.

Coil L_1 constitutes the anode load of both valves, and its inductance, in conjunction with capacity C_4, will determine the frequency of oscillation.

The impedance, or dynamic resistance Z, of the circuit $L_1 - C_4$ at resonance is given by the well-known equation $Z = L/CR$, where the units are fundamental, *i.e.*, L is in henries, C in farads, R in ohms.

The Q of such a circuit is the relation of R to Z, *i.e.*, relation of resistance to impedance, and is a measure of the efficiency of the circuit.

To obtain the best load factors possible in radio heating, it is essential to commence with a tank circuit designed to have as high a value of Q as possible, somewhere around 100. When the load of the work is placed across the tank, it will be equivalent to a parallel impedance, and so will reduce the impedance of the tank circuit—from the resistors in parallel formula,

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

Since Q is, in a parallel circuit, defined as the ratio of parallel resistance to impedance, then this will reduce the Q of the circuit and thus enable the valve to work efficiently and to transfer the maximum amount of power to the load. The most efficient figure for Q under load conditions is 10, and this also is the lowest value Q may possibly have. The reason for this is that with a Q lower than 10, the percentage harmonics in the output wave form become very high, and in addition to this the tank circuit will have a low power factor for presentation to the valve, both conditions being extremely wasteful of power. Unfortunately space does not permit proof of the foregoing statements, but detailed expositions will be found in any good text book.

The power in the circuit which is available for transfer into the "work" will be dependent on the A.C. voltage present, as this is the only power that can do work by virtue of the alternating field it produces.

The peak alternating voltage present in the circuit will be the high tension voltage minus the minimum anode voltage, *i.e.* :—

$$E_{ac\,.\,max} = E_{ht} - E_{a\,min} \qquad (3)$$

Since it is power transfer that is under consideration, R.M.S. voltage will have to be substituted for peak voltage. Therefore,

$$E_{ac\,.\,RMS} = \frac{(E_{ht} - E_{a\,min})}{\sqrt{2}} = \frac{E_{ac\,max}}{\sqrt{2}} \qquad (4)$$

This voltage is developed across the impedance L/CR, where R is the series resistance of the coil. As this impedance is the anode load of the valve, then it must be given an optimum value at operating frequency. This optimum value is found as follows :—

It is first necessary to express the resonant impedance of the circuit in terms of Q, frequency, and inductance, so that, as the resistance of the condenser can be ignored at frequencies under 30 megacycles/second, and $Q = \frac{2\pi f L}{R}$ by definition,

$$\text{Then,} \quad Q = \frac{2\pi f L}{R}, \text{ and } \frac{L}{CR} = \frac{2\pi f L}{R} \times \frac{1}{2\pi f C}$$

$$\text{Therefore,} \quad Q \times \frac{1}{2\pi f C} = \frac{2\pi f L}{R} \times \frac{1}{2\pi f C} = \frac{L}{CR}$$

$$\text{As} \quad \frac{1}{2\pi f C} = 2\pi f L \text{ at resonance,}$$

$$\text{Then} \quad Q\,2\pi f L = \frac{L}{CR} \qquad (5)$$

The power in watts in a circuit with unity power factor, expressed in terms of R.M.S. voltage and resistance is :—

Watts $= W = \frac{E^2}{R}$, so that, taking voltage from equation (4) and dynamic resistance from equation (5),

$$W = \frac{(E_{ac\ RMS})^2}{Q\,2\,\pi f L} \qquad (6)$$

This equation (6) can then be re-arranged in the form :—

$$2\,\pi f L = \frac{(E_{ac\ RMS})^2}{Q\,W} \qquad (7)$$

which, solving for L in micro-henries, becomes

$$L = \frac{(E_{ac\ RMS})^2 \times 10^{-6}}{Q\,W\,2\,\pi f} \qquad (8)$$

where f is frequency in cycles per second.

In push-pull circuits each valve is designed around its own operating characteristics, but in the case of equation (8) the value of L found will have to be doubled, because the voltage E, found from equation (4) is only for one valve. In push-pull, the power is doubled, hence the need for optimum load to be twice that necessary for one valve.

(*g*) CONDENSER C_4.

The value of this component will follow from equation (8).

(*h*) FEEDBACK TAPS.

Will be so proportioned to feed correct peak R.F. voltage to grids.

7. The Oscillator. (Dielectric Heating).

The design of an oscillator for dielectric heating follows on closely similar lines to the eddy current heater, the main difference being that instead of power amplification the requirement is now voltage amplification. This is because, in D.H. (dielectric heating), the energy passed to the work is proportional to the voltage developed across the tank circuit, and not, as in E.C.H. (eddy current heating) the current flow. High voltages are obtained with low power by using valves having a high anode impedance, since, for given power dissipation, the alternating voltage component in the tank circuit will be greater the higher the anode impedance.

This allows quite small valves to be used in D.H., sometimes with anode dissipation figures under 10 watts.

8. Output Circuits.

(*a*) INDUCTION HEATERS.

Fig. 12 shows the work coil coupled by the "auto-transformer" method, although the inductive coupling is not usually close enough to enable the hook-up to be regarded as a true auto-transformer.

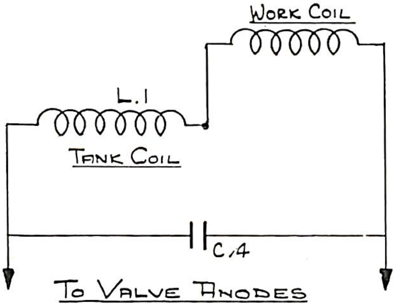


Fig. 12.—"Auto Transformer" Coupling.

This means that the degree of matching obtainable is not very high, hence this method of coupling is generally used only where powers handled are above 5 kilowatts.

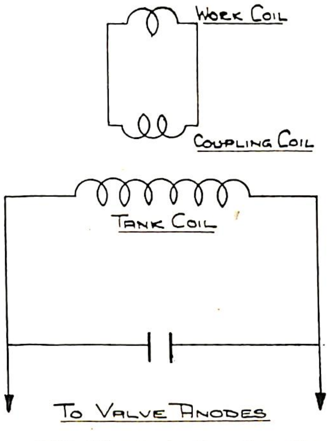


Fig. 13.—Inductive Coupling

Fig. 13 is an example of inductive coupling. This allows matching to be performed with a fair degree of accuracy, although the losses in the closed circuit coupling are rather high. The overall turns ratio of the coupling, work, and tank coils, which in effect constitute two transformers, can together be used for matching work to tank coils. This type of magnetic coupling is used for powers below 5 kilowatts.

(*b*) DIELECTRIC HEATERS.

In Fig. 14 the work is placed directly across the tank coil, condensers C_{1A} - C_{2A} serving merely to act as H.T. stoppers, preventing the work electrodes becoming "alive." The work being

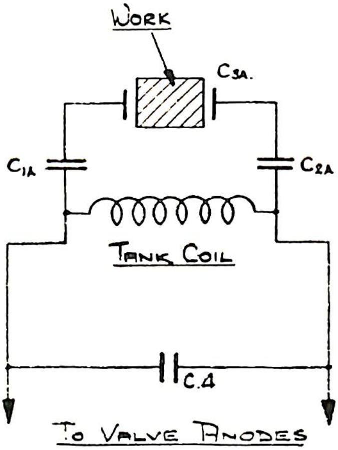


Fig. 14.—Shunt Coupling.

heated constitutes the dielectric of condenser C_{3A}. With this method there is no provision for ensuring optimum transfer of energy from oscillator to work, so that the method shown in Fig. 15 is more generally employed.

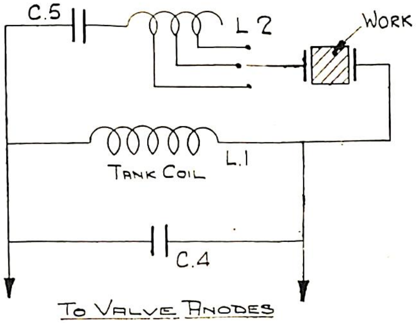


Fig. 15.—Series Tuned Coupling.

This circuit (Fig. 15) constitutes a series tuned combination of inductance and capacity L_2 - C_5. At resonance this circuit will possess minimum impedance to current at the resonant frequency, and therefore current flow will be maximum. This means that the voltage across the reactive arm of the circuit will be at maximum.

In all methods of coupling, whether for E.C.H. or D.H., the aim is to commence with a tank circuit Q of a value as high as possible under "no load" conditions, and arrange for the Q on load to come down to about 10, thus enabling the greatest amount of power to be developed in the load.

CHAPTER II.

ELECTRONIC CONTROL METHODS.

1. The Thermionic Valve.

One of the main advantages of the three-electrode thermionic valve is the ease with which small variations of voltage on one electrode, called the grid, can produce large variations of current flow in the valve. In one special type of valve, usually termed a "gas-filled" valve or "thyratron," an exceptionally heavy current can be started and stopped by means of a very small potential applied to its electrodes.

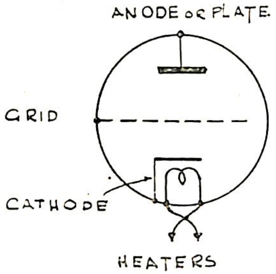


Fig. 16.—Triode Value.

A symbolic representation of a normal type of three-electrode valve or triode is given in Fig. 16. In the triode valve, the grid is placed very close to the cathode, while the anode or "plate" is placed a relatively great distance away. Because of its proximity to the cathode a small voltage change on the grid will have the same effect on the electron stream as would a very much larger voltage change on the anode. The grid of a valve is usually kept negative with respect to its cathode in order to prevent an inordinately high anode current from flowing, and this negative voltage applied to the grid is generally termed the "grid bias." The amplification factor of a valve is the ratio of change in grid volts to the change in anode volts that would be necessary to produce the same change in current flowing. That is,

$$\text{Amplification factor } (\mu) = \frac{\text{Anode volts change}}{\text{Grid volts change}}$$

2. The Thyratron.

The gas-filled valve (thyratron) mentioned before contains a small amount of chemically inert gas, and this gas enables the thyratron to carry a very much heavier current than a vacuum valve of the same physical size. This is because when anode current begins to flow, the gas in the valve becomes ionised, and as the grid is the most negative electrode in the tube, the relatively heavy positive ions drift on to it. This makes the grid less negative, enabling more electrons to flow, ionising more gas atoms, the grid becomes even less negative, and so on. This cumulative process accounts for the rapid rise in anode current that takes place in a thyratron, this rise being maintained even against a drop in anode voltage.

The high rate of discharge of a thyratron makes it very suitable for use as a relay valve. The principle of operation is this. When a condenser is charged through a resistance, the voltage across the condenser rises relatively slowly, at a rate depending upon the values of the condenser and resistance. If the voltage across the condenser is plotted against time, the resulting curve is exponential in character; thus a condenser is said to charge exponentially. (See Appendix 1).

A thyratron connected across the condenser and biased to a certain figure will conduct when the voltage across the condenser has reached a certain limit. This positive value is high enough to overcome the negative voltage on the grid, and it will be much greater than this grid voltage. The condenser then discharges, and current flows through the valve at a rapidly increasing rate, and can be made to do work by passing through a load in the thyratron's anode circuit (the relay—Fig. 17).

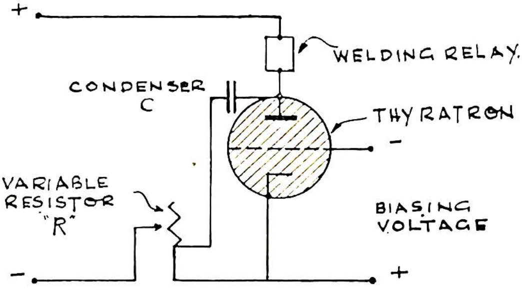


Fig. 17.—Thyratron Circuit.

To obtain a pulse of short duration, the product of capacity multiplied by resistance, C × R (Fig. 12) must be small, whilst pulses of long duration depend upon C × R being of high value. One important application of a thyratron relay is in electric welding. Here a thyratron is arranged to charge up through a resistance and condenser, the values of both being so arranged that the point at which anode current commences to flow (the "striking" voltage of the thyratron) is reached after a required length of time has elapsed. Due to the action of the thyratron as explained, a current sufficiently heavy to actuate a powerful magnetic relay will be flowing almost instantaneously. The relay is arranged to start and stop the high amperage welding current, the cut off being manipulated by the operator or by an "inverter" type of circuit, as described on page 25. Accurate control of duration of current flow is of great importance in welding, and electronically controlled relays enable this accuracy to be achieved in a reliable manner.

A basic circuit for welding control is given in Fig. 12, and the welding relay shown can incorporate a time delay for self-resetting, thus making a completely automatic control system, using only one valve.

3. The Ignitron.

The foregoing apparatus, used generally to control flash or resistance welding cycles, is very efficient up to a capacity of about 130 kilovolt-amps. When the capacity of the machine rises above that figure, the size of the relays needed becomes prohibitive, and, in addition, a relay or contactor to handle above 300 amps at 400 volts, would be necessarily both noisy and slow in operation.

It is here that a new type of control is brought into use, a valve termed an "ignitron."

The ignitron consists of a three-electrode valve, one electrode being the anode, one the "igniter" and one a mercury pool cathode. The igniter is a cone-shaped piece of semi-conducting material, with its small end just dipping into the pool of mercury constituting the cathode, and the method of operation is this :—

A current is passed from the igniter through the mercury pool, forming a local "hot spot," and thus releasing electrons from that spot. If the anode of the igniter is positive with respect to its cathode, then a current will flow through the valve. This current can have a momentary value of several thousands of amps, and thereby does away with the necessity of using a relay, as the actual current flow through the valve can be the welding current. The value of current can vary through wide limits, as the drop of voltage across the valve remains fairly constant around 20 volts, irrespective of current flow.

Another use for the gas relay valve is in the control of high-speed machine mechanisms, where instantaneous control of large currents is required, with the minimum expenditure of mechanical effort.

In controls of this type a slight mechanical movement is arranged to operate a wafer switch which applies a small positive potential to the grid of the thyratron, reducing its bias from, say, minus 10 volts to minus 5 volts. If the anode was arranged to start current flow with the grid 10 volts negative, then reducing grid bias to 5 volts negative, will permit the anode voltage to "strike" in half the time it would otherwise have needed. This has the effect of setting off the cycle of events, although the anode has not reached the originally determined striking voltage.

This allows a more accurate time control to be maintained, and when operated in this manner the thyratron is said to be "triggered."

2. The Inverter.

Another, and very interesting, use of the gas relay type of thermionic valve is in an "inverter" circuit. This circuit enables direct current to be converted into alternating current without the use of any moving parts, other than electrons.

Normally, when a higher voltage than that provided by D.C. mains is needed to operate an amplifier or radio receiver, the D.C. is first changed into A.C. by a rotary converter, or vibrator unit, and then rectified. Both these processes utilize a mechanical movement for the conversion of the D.C. into A.C.

With the thyratron this conversion is accomplished entirely by electrical means, with a consequent abolition of noise and increase in efficiency. The type of circuit that uses thyratron valves to achieve this result is termed an "inverter," and a skeleton circuit is given in Fig. 18.

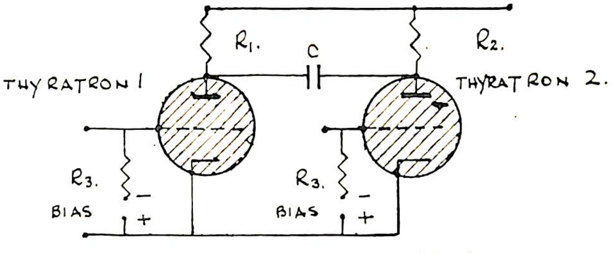


Fig. 18.—Skeleton Inverter Circuit.

In operation, an impulse is applied to the grid of thyratron 1, causing a current to flow in the anode circuit and through load resistance R_1. The condenser C also charges through the second load resistance R_2, and it charges until its potential is nearly equal to that of the high tension supply. This is because, although connected to the anode of thyratron 1, the condenser is in effect directly across the H.T. supply because when current is flowing through thyratron 1 its resistance is negligible. Now, suppose a second impulse be applied, but this time to the grid of thyratron 2. Current flows through this valve, and, as its resistance is now very low, due to this current flow, the end of condenser C connected to its anode is in effect tied to H.T. minus. As this end of condenser C was at high potential, due to the first impulse applied to thyratron 1, and is now tied to the low potential end of the circuit (H.T. minus) through thyratron 2, it must discharge through this valve. Its potential is thus applied between anode and cathode of thyratron 1, and in such a direction as to oppose the H.T. voltage applied to this valve, and consequently current through it ceases. This leaves the first valve quiescent, and it can only be made to conduct again by the application of an impulse to its grid, *i.e.*, it must be triggered.

Before this impulse is applied, C is charged in the opposite direction through load resistor R_1.

The next impulse is now applied to the grid of thyratron 1, causing it to pass current as before.

Condenser C now discharges through this valve, thus extinguishing the current in thyratron 2. This continues as long as timed impulses are applied to each grid in turn, and the resulting current flow in the output circuit will be alternating. This A.C. can be transformed to any required voltage, and then rectified for use in any H.T. circuit.

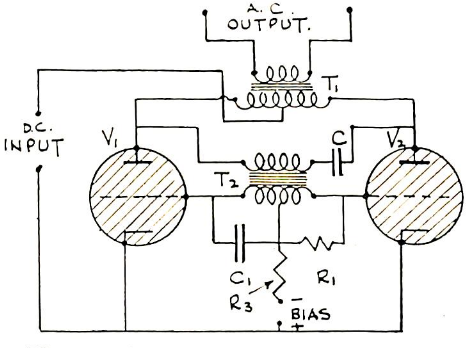


Fig. 19.—Inverter Circuit (Self-Timing).

Fig. 19 shows how the thyratrons are made to supply their own correctly timed impulses, and the frequency of the output A.C. is dependent on the values of R1 and C1, as these time the impulses to the grids.

T1 is a centre tapped transformer, through the primary of which D.C. is applied to the anodes of V1 and V2.

T2 is again centre-tapped, this time the secondary tap is used for applying a negative voltage to the grid.

Small inverters for power amplifying equipment and radio receivers can be constructed using Osram G.T.1 or Mazda T.11 type thyratron, and these provide a very efficient H.T. supply when used in conjunction with universal type rectifiers.

CHAPTER III.

PHOTO-ELECTRIC CELLS.

A photo-electric cell is primarily a means of either converting light energy into electrical energy, or using light energy to control electrical energy. These properties make photo-cells one of the most used and most useful devices available to industry.

There are three main types of photo-cell, the first being called "photo-conductive," the second "photo-emissive" and the third "photo-voltaic."

The photo-emissive cell is more versatile and in more general use than its predecessor, the photo-conductive, but an explanation of the latter will be of help in understanding the slightly more complex action of the photo-emissive and voltaic types.

The original discovery that light energy could be used to influence electrical energy was reputedly made at an early Trans-Atlantic radiotelegraph station of Marconi's, where it was observed that the resistance of a selenium strip decreased when a beam of sunlight fell across it. This discovery was followed up, and the selenium photo-cell is the result.

1. Photo-Conductive Cells.

These cells are made by depositing a very thin layer of metallic selenium on to a foil electrode, the whole being assembled on a glass base. The whole is then heat-treated to convert the selenium to a sensitive crystalline state.

In complete darkness a selenium cell's resistance is about three million ohms, but when strongly illuminated falls to around forty thousand ohms. To use the cell it is usual to include it in the grid circuit of a valve amplifier, as in Fig. 20.

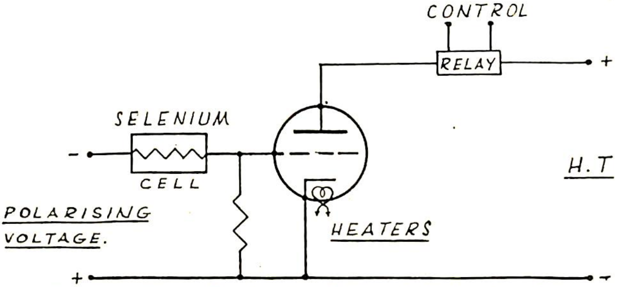


Fig. 20.—Photo-Conductive Cell and Valve Amplifier.

All photo-conductive cells must have a constant voltage applied to them, as they can only control current, not generate it.

2. Photo-Emissive Cells.

These are more truly "photo-cells," as they do actually emit electrons when placed in the path of a light beam. The construction of one of these cells is shown in Fig. 21.

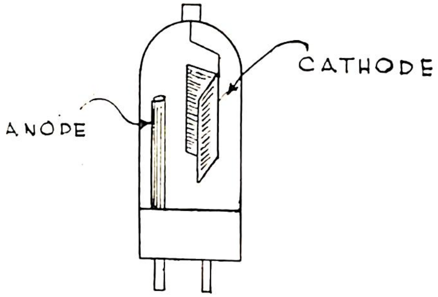


Fig. 21.—Photo-Emissive Cell.

The cathode of an emissive cell usually consists of a thin metal plate coated with sodium, or caesium, depending on the colour of the light to which the cell must respond.

Several metals possess the property of emitting electrons under the influence of light, and in addition to sodium and caesium already mentioned, potassium and rubidium constitute the more efficient of the photo emissive series.

Some of these metals respond more readily to light of one colour than another, the most notable being sodium, responsive to blue light, and caesium, sensitive to green. One of the most modern types of caesium cell, consisting of a caesium film a few molecules thick deposited on a backing of oxydised silver is sensitive to all colours, and slightly more sensitive to violet and red. With the emissive type of cell the electrode assembly is mounted inside a glass bulb which can be either evacuated completely—when it is termed a "hard" cell—or have a trace of inert gas left in it, when it is a gas-filled or "soft" cell.

The gas-filled cell has much higher output owing to ionisation of the gas left in its bulb, but is more critical regarding anode voltage, and cannot respond to rapid fluctuations of light intensity such as occur in a talkie projector. For these reasons the "hard" cell is more favoured to-day.

Two main forms of circuit are used for the photo-emissive cell, depending on whether light is shone on to or cut off from the cell. In these cells an anode voltage is necessary in order to "drag off" the released electrons exactly as in the case of the thermionic valve.

When the cell is in darkness no electrons are emitted from its cathode, and the cell is of such a high resistance as to be equivalent to a break in the circuit between H.T. and grid (Fig. 22), consequently the grid of the valve is kept negative by the bias voltage

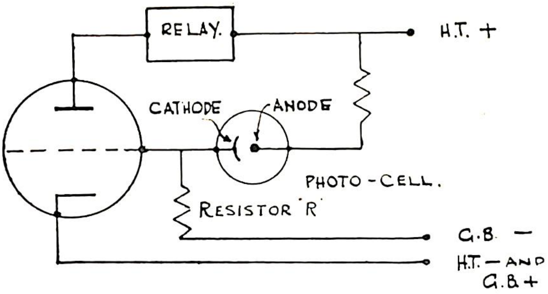


Fig. 22.—Photo-Emissive Cell and Valve Amplifier.

applied to it. This negative bias nullifies the effect of the anode voltage on the valve, no electrons are removed from its cathode, and no current flows through the relay. When the cell is illuminated, electrons are emitted from its cathode and attracted to the anode, because the anode is connected to H.T. plus. This electron flow generates a voltage drop across resistance R in opposition to the bias voltage on the grid, so current flows through the valve and the relay closes.

To make the cell operate when light is cut off from it, it is only necessary to reverse the cell and the battery connections. In this case, the voltage generated across R is of the same polarity as the bias voltage, and so the bias on the valve is increased when light shines on the cell, and anode current through the valve only flows when light is cut off, and thus the relay acts when the light beam is interrupted. It is this circuit that is used to guard safes, jewels, etc., and is the basis of photo-electric alarm signals. The cell will respond to ultra-violet light which is invisible to the human eye, and so can form a perfect protection device, the existence of which will be unnoticeable.

Applications of the circuit using a closed relay when the cell is illuminated are so numerous as to defy tabulation, but some of the more important ones may be mentioned. It can be used to safeguard a power press operator, in which instance a light source, such as an electric lamp, is placed on one side of the press and a photo-cell on the other. When the operator's hand or arm interrupts the light beam the relay in the valve circuit is caused to disconnect the press motor or clutch mechanism, and thus prevent the downward stroke of the press from taking place. The photo-cell would be provided with a hood to ensure that only light from the proper fixed source could operate it. The cell would not work on the upward stroke, so no time need be lost and work could be placed in the press whilst the ram was ascending, perfect safety being ensured by the cell.

Light variation due to marks on the paper can be utilized in the control of a wrapping machine, and the exact matching of colours is possible by using several cells, each one responding to one colour only, and arranging each output to register on meters marked "% red," "% blue" and etc. The actual resulting colour can then be arrived at. The colour response of the cells would be obtained by placing a different colour filter in front of each one.

Photo cells are used on printing machines, where they stop the whole press within 15 secs. of the paper breaking, preventing damage to expensive plates, etc. Fig. 23 shows a photo-cell fixed in a coal hopper in such a manner that visual indication is given of coal level. Cells are also used in lifts to stop the lift at exact floor level; as incendiary bomb and fire detectors, when they are also arranged to turn on the sprinkler system; and as automatic door-controls in places such as mines, where failure to close a door may have serious consequences in event of an explosion.

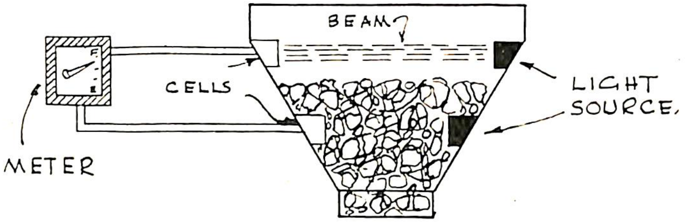


Fig. 23.—Photo-Cells in Coal Hopper.

An interesting application of a cell of either the photo-emissive or photo-conductive types is when used as a smoke density meter. This is done by using a photo-cell, an amplifier, and a light source. The photo-cell is placed at the top of the stack, and the light source fixed opposite it. When the smoke density reaches a pre-determined level, the output of the cell falls and operates a warning device that can be either aural or optical.

3. Photo-Voltaic.

This cell differs from the other two in that it does not require an energising voltage, because, as its name suggests, it generates its own power. It may, in fact, be likened to a miniature electricity works, where the current is generated by light instead of coal and turbo-alternators.

The action of the cell depends on the fact that when light strikes certain semi-conducting materials electrons are forced out of the materials and will pass into any contacting conductor. The metals used are copper in contact with copper oxide, or selenium in contact with iron.

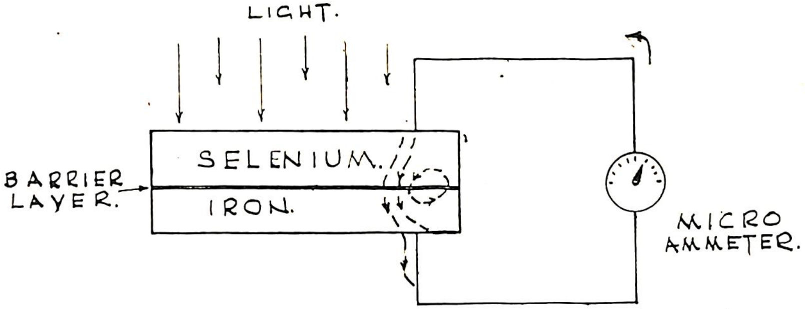


Fig. 24.—Photo-Voltaic Cell.

Fig. 24 illustrates the action of one of these cells. When light penetrates the selenium, which is actually a very thin film, it releases electrons at the junction of the selenium and iron layers. This junction point is generally termed the "barrier layer."

A sensitive current indicating meter (micro-ammeter) connected as shown, will be deflected when light falls on the cell, thus showing the passage of an electric current. This cell is used in "light meters" of all kinds, and in the photographers' exposure meter. Its output is much higher than that of its brother, the emissive type, and, of course, it does not need the polarising voltage that the emissive and conductive types do.

All photo cell apparatus, large or small, consists of the following parts :—

1. Light source.
2. Photo cell, with valve amplifier if necessary.
3. Relay, or some indicating, registering, or recording apparatus.

CHAPTER IV.

MATERIAL CONTROL.

1. Raw Materials.

In addition to the already mentioned method of radio-frequency melting of special steels, there exist several types of electronic equipment adapted for testing and controlling materials throughout the whole of their manufacture.

Among this apparatus may be mentioned the useful type of radiation pyrometer used for measuring various temperatures. It consists of a thermocouple placed at the focus of a parabolic reflector, arranged to record the temperature of flowing metal, rather than that of the furnace.

Thermocouples can be made so sensitive that they will measure the heat of a candle at a distance of more than a mile. Inspection of raw material by X-rays is in quite general use, but on the whole X-ray analysis seems to be more profitably employed in the finished article, and will be dealt with later.

A very recent system of checking bar and strip metal is by the oscillograph principle. Here, a bar of metal of known quality is used as a standard, and the consignment to be checked is compared with it in the following manner. The standard bar is fixed on a machine in such a manner that it can pass axially through a coil of wire, and the bar to be tested is arranged to pass through a second coil in an identical manner.

The coils carry a low-frequency alternating current—25 cycles per second has been found to be best—and the inductance of the coils arranged to register on a cathode ray oscillograph. The coil through which the standard bar is being moved will show small variations, and limits of acceptance or refusal will be set, having regard to these differences. The bar under test should show the same variations as the standard bar, and if these variations fall outside the "go" limits, then the bar will be automatically marked as unserviceable.

Slag lines, blow holes, inconsistent thickness, etc., will all show up on the oscillograph, and the bar will be marked where these faults occur.

There are several variations of this comparator method, one of which depends on the eddy current principle, but all of them are basically similar in operation.

2. Crack Detection.

One of the earliest patents taken out for crack-detecting apparatus was the American one, and it used the system shown diagrammatically in Fig. 25.

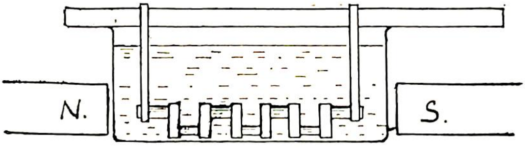


Fig. 25.

Very fine particles of iron were mixed with oil, and the article to be inspected for cracks immersed in the liquid, and the whole was then placed between the poles of a powerful electro-magnet. Any break in the metal will have a magnetic field existing across it, and consequently the fine iron filings will adhere to the gap. The depth or amount of "piling" of the iron is roughly proportional to the depth of the fault.

With this method the biggest trouble was maintaining the iron particles in suspension, and however fine they were made it was still necessary to use a fairly viscous medium to effect any reliable degree of suspension.

The obvious alternative was to use a magnetic oxide of iron, and this was done eventually. The suspending medium eventually used was a paraffin oil, and a specially light, porous oxide of iron developed for use with the oil. There are also various powders obtainable which serve the same purpose, but in principle the apparatus remains the same.

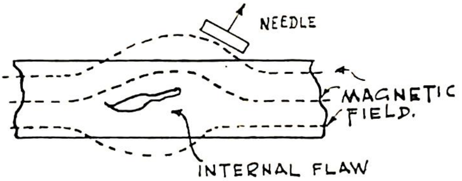


Fig. 26.

Another method shown in Fig. 26 enabled flaws to be detected in the interior of apparently crack-free material.

The magnetised needle is traversed along the lines of magnetic flux flowing through the material, and if, by reason of a flaw or some other distortion the free flow is interrupted, then a bending of the force lines will occur. So long as these bent flux lines extend outside the job under test, then the needle will follow their change of direction and thus indicate the fault.

It will be noticed that cracks, etc., can only be detected magnetically when they lie at an angle to the direction of the magnetic field, and therefore the article should be magnetised in two directions at 90° to each other. Non-magnetic materials cannot, of course, be inspected in this manner, and there are several methods of eddy current crack detection for these cases.

One of the latest developments in the detection of surface flaws is the use of ultra-violet light. It is a very simple method, is easily carried out, and can be applied to most substances, metallic or otherwise.

The article under test is first subjected to a degreasing process, and then dusted over with a very fine light powder that has the property of fluorescing under ultra-violet light. The excess powder is then removed but, because of its extreme fineness, a quantity will remain in even the smallest crack or surface flaw. It is then placed under a strong ultra-violet lamp, and the powder remaining in the cracks glows brightly—that is, it "fluoresces." The phenomenon of fluorescence is a very interesting one, and it involves a process whereby the fluorescing material absorbs the light energy falling on to it, and re-radiates part of this energy in the form of light of a longer wavelength, or of a colour nearer to the red end of the spectrum.

The light used in this method of crack detection is ultra-violet, and it is of such a short wavelength as be invisible to the human eye. Consequently, when the job being inspected is viewed in a darkened room, only the light from the fluorescing material remaining in the surface faults will be visible.

In a system demonstrated by Colloidal Research Laboratories Ltd. the article to be examined is first placed in a hot bath of fluorescent material, and then transferred to a bath containing a solution which removes all fluorescent material except that remaining in cracks, etc. It is then exposed to ultra-violet light in the usual manner.

The normal technique of dipping in the two baths can be varied to suit special cases, and the method is marketed under the trade name "Geo-Crack System."

3. Radiography.

X-rays, ultra-violet rays, visible light, and broadcast radio waves differ from each other by wavelength alone, and are all in what is termed the "Electromagnetic Spectrum," Fig. 27 illustrates this in diagrammatic form, and the terms "rays" and "waves" are really synonymous.

Long Radio Waves	Medium Radio Waves	Short Radio Waves	Ultra Short	Micro Waves	Infra-Red Rays (Heat)	Visible Light	Ultra Violet Rays	X Rays	Gamma Rays	Cosmic Rays

Fig. 27.—Electromagnetic Spectrum.

X-rays have the valuable property of being able to penetrate quite considerable thicknesses of material, and they also affect photographic plates in much the same manner as does ordinary light. Hence it becomes possible to photograph the "inside" of metals or objects that are otherwise completely inaccessible. There are two main ways of carrying out inspection by X-ray, one by means of a fluorescent screen, and the other by photography.

In the first case the object to be "analysed" is placed between an X-ray tube and the fluorescent screen, when an outline of the object and its internal construction will appear on the screen. This system, whilst being fast and cheap, needs a highly-skilled operator, owing to the difficulty experienced in visualising the resultant picture in its true perspective.

With the photographic recording of X-rayed objects, interpretation becomes much easier, and fault detection is 7 to 10 times more accurate. The image will not be reversed, and comparatively unskilled labour can be used for operational purposes. The film is usually passed through a projector and the enlarged reproduction viewed on a screen.

The uses of X-ray photography are too numerous to permit mention of every individual application, but among the more unusual ones are X-ray inspection of soldered joints, plastic mouldings, the flow of dust in exhaust tubes, and, with an X-ray tube working at 1,000,000 volts, photographs through 8″ thick steel plate. The use of radiography in foundry inspections not only eliminates the further processing of faulty castings, but helps toward better foundry practice in general.

Where the shape of the object or its location does not permit the use of an X-ray set, then it is often possible to obtain the same sort of photograph with the help of gamma rays. These rays are emitted by most radio-active substances, have a penetrating power equal to or surpassing that of X-rays, and affect film in the same manner.

Usually the gamma ray source is 200-250 milligrams of radium element sealed into a platinum capsule, and its diminutive size makes it suitable for photography from awkward situations.

4. X-Ray Crystallography.

X-ray crystal analysis is taking its place in routine inspection matters, and has ceased to be regarded as a pure research instrument. As a rule, moderately dense materials such as metals do not show a distinct surface crystal structure with any degree of symmetry. However, their internal granular structure is dependent upon a regular atomic disposition, and it is this regular arrangement of internal atoms that helps determine their physical properties. For most metals used industrially, the basic crystal structure is either body-centred cubic, face-centred cubic, or hexagonal.

As the spacing of the planes in these crystals is approximately the same as the wavelength of X-rays, they act to these rays as diffraction gratings do to ordinary light. From this basic knowledge a method has been devised which enables substances to be analysed by virtue of their crystal nature, instead of depending on chemical means. Crystal analysis has also proved exceptionally valuable in research on synthetic rubber, plastics, gaseous discharge lamps, etc., and there is no doubt that it will become even more valuable as time goes on.

CHAPTER V.

GENERAL.

1. Electron Microscope.

The electron microscope claims to be the most sensational instrument of the age, and represents one of the biggest strides made in electronics during recent years. Its advantages over the ordinary type of optical instrument are as great as was the increase in performance given by the light microscope over the magnifying glass of years ago.

Briefly, the limitations of the light or optical microscope are imposed by the fact that the wavelength of light is too long to allow direct magnifications higher than about 2000 times. If invisible ultra-violet light is used and the object viewed through quartz lenses and a fluorescent screen, then a gain of 50% or so can be obtained ; this because the wavelength of ultra-violet light is very much shorter than that of the blue-green light usually used. From this followed that, until it should become possible to develop an entirely different system of magnification, the ultimate end of microscopy had been reached.

About 20 years ago it was shown by de Broglie that a travelling electron has a definite wavelength, and, that this wavelength could be evaluated mathematically. His formula expressed this wavelength in terms of the voltage accelerating the electron, and, where this voltage is E, was :—

$$\text{Wavelength} = \sqrt{\left(\frac{150}{E}\right)} \times 10^{-10} \text{ meters.}$$

The value E for metal cathode ray tubes is in the region of 60,000 volts, and gives a wavelength of ·05 × 10^{-10} meters.

With the electron stream as a basis in the new electron microscope, the useful magnification obtained may be increased 100,000 times that possible with ordinary light, and so the claim of the electron microscope to be the most sensational instrument of the age is well supported. The electron microscope works on very much the same principle as does the ordinary optical instrument, the main differences being that, as already shown, an electron stream is substituted for a light ray, and electro-static or electro-magnetic lenses are used in place of the glass or quartz ones of the light microscope.

These electronic lenses are of exactly the same type as those shown in Figs. 3 to 6 inc. Commercial instruments are marketed by R.C.A. and the G.E. Company of America, and vary in magnifying power from 8000 x in a G.E. electrostatic model, to R.C.A.'s 6-ft. high floor model, giving magnification up to about 200,000 x.

2. Ozone Generator.

An ozone generator utilizes a "brush" discharge of electricity to produce a molecule of oxygen with the formula 0_3. This somewhat unstable molecule is a very active bleaching and oxydising agent.

A big use for an ozone generator is in canteens or workshops using malodorous processes, where it will keep the air free from taint, in addition to acting as a good germicide.

Ozone does not get rid of odours merely by masking them with stronger and more acceptable ones ; it actually destroys them by entering into chemical combination—in effect, it burns up the offensive particles.

The principle of operation is very simple, and the apparatus consists of an arrangement of small sharply-pointed electrodes, from which a continuous discharge of electricity, called a brush discharge, is obtained. Any electric spark will produce ozone, but as a spark is accompanied by heat, it also generates nitrogen oxide and, by virtue of its heat, tends to decompose the ozone back into oxygen. Hence the use of a brush discharge type of generator which is easily able to dissipate the very small amount of heat it produces.

3. Measuring Instruments.

Although electronics has provided us with innumerable precision instruments, each and every one employs one or other of the accepted basic principles of electronics. As a consequence, no useful purpose would be served by making what would amount to an incredibly long list of instruments that would most certainly omit the majority of types available. One of the later measuring instruments that is especially worthy of note is the "vibration meter." This instrument consists essentially of an integrating valve voltmeter, and in effect is used to measure the voltages developed by a piezo-electric crystal. The crystal is mounted in a housing (called the "pick-up head") which is clamped to the part under test, and naturally picks up the vibration of that part. These vibrations are transferred into electrical impulses by the crystal in exactly the same manner as in a crystal gramophone pick-up, or a crystal microphone, and then fed to the valve voltmeter. The scale of this voltmeter is calibrated in thousandths of an inch instead of in volts, and thus gives a direct indication of the amount of vibration present. If this instrument is used in conjunction with a cathode ray oscilloscope, a direct reading of the frequency of vibration can also be obtained.

Another interesting use of meters is in connection with boiler house control. Boiler indicating instruments, such as CO_2 indicating recorders, pressure gauges, smoke density meters (page 30), etc., can be set in a panel in the boiler house and arranged to operate remote-control mechanism.

A duplicate set of these instruments may with advantage be situated in the office of the chief engineer, the whole boiler house system then being under constant skilled supervision. A much higher average efficiency can thus be maintained with less time lost due to breakdowns. The principle of remotely controlled electronic instruments is not applicable solely to boiler house work. It can be used wherever a process or machine requires constant control. In some cases, relays can be connected to the instruments concerned in such a manner as to make them self-regulating, and the machine or process completely automatic.

4. Discharge Tubes.

One of the earliest gas-discharge tubes ever made was the "Geissler" tube, produced in 1880. (Fig. 28).

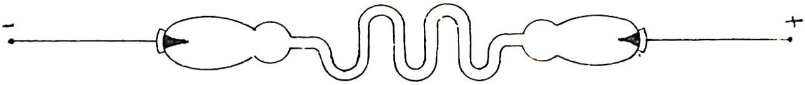


Fig. 28.—Geissler Tube.

This is a glass tube, from which air has been exhausted, and two platinum or nickel wires sealed into it, one at each end. If an electric potential be applied across it, then, depending on the pressure of the gas remaining in the tube, a coloured glow will be emitted. The distribution of the glow is controlled by the pressure existing in the tube, and the colour is determined by the nature of the gas causing this pressure. The phenomena of glow distribution change with pressure change is made to perform a very useful job in the food canning industry, where it provides a rapid and reliable indication of the state of vacuum existing in the air exhausting apparatus. The colour of the light is dependent on both the pressure of the gas and its nature, and so provides an additional check, indicating the presence of gaseous impurities that might condense after the cans are sealed. Water vapour and oil vapour are likely offenders, and they would make their presence known by a whitish-blue or blue glow respectively.

In this method of pressure indication a small tube of specially toughened glass between 10-20 cms. long is permanently attached to the vacuum chamber, and a fairly high voltage maintained across its electrodes.

The colour of the glow in the tube and the disposition of this colour then gives a sufficiently reliable general indication of the degree of vacuum existing.

This type of pressure measurement is also used in instances where chemicals are to be distilled in vacuo, and in the evaporation of metals in laboratory work.

5. Fluorescent Lighting.

Modern fluorescent lighting tubes are made in lengths up to five feet, and are what is called the "hot cathode" type. They are also obtainable with the inner glass walls coated with a fluorescent powder, and the powder is so chosen that in conjunction with the glow from the gas itself a light closely approximating to daylight is produced. Hence the name "daylight lamps." Compared with the ordinary incandescent filament lamp fluorescent lighting is very efficient, giving more light per watt, and the tubes have a life slightly longer than the familiar tungsten bulb. Their surface brightness is about double that of the ordinary lamp, and to compensate for this, the general degree of illumination should be increased ten times.

Light intensity levels are very rarely taken as high as this, and so fluorescent lamps should not be mounted in direct view.

A special type of discharge tube known as the "Strobotron" has been recently developed for high-speed photography. This tube gives a very intense flash of light lasting only a few thousandths of a second, and special tubes have been developed giving a flash discharge lasting only 1/40,000 of a second. They are used in the photography of high-speed machines, such as the reciprocating parts of internal combustion engines, and in scientific work of every kind.

It should be mentioned here that although the term "fluorescent lighting" is now applied to most gas-discharge tubes, it is not strictly correct. The only lamps that are truly fluorescent are the "daylight" or "warm-white" types, the others being more strictly termed "gas-discharge" lamps.

6. Sound Amplification.

One of the most well-known uses of high power amplification is the diffusion of music, etc., in factories, including the relaying of the B.B.C.' "music while you work" programmes. The usual type of equipment used is built on the rack principle, incorporating record-playing desk with turn-table and pick-up, radio receiver, and controls for "fading" in the microphone used for making announcements.

In factories where there is likely to be a large amount of iron dust flying about in a dirty atmosphere, special types of industrial speakers must be used. These are protected from dust and damp, and have especially efficient protection from small particles of iron and iron filings. As these speakers are of the permanent magnet type, they attract iron dust and any other magnetic material in the atmosphere, hence the necessity for special insulation. When the speaker unit has to be fixed in a machine shop where there are extensive overhead countershaft systems then a directional type of horn speaker is used. This directional property enables the unit to be placed well above the shafting, and the sound output directed down to the level where it is required. If it should be thought necessary these directional speakers can be "aimed" at a particular group of workers, or directed at an area having high noise level, thus overcoming interference without a large expenditure of energy over areas that do not require it. In addition, an application of the well-known "automatic volume control" principle will enable an amplifier to adjust itself to varying noise levels.

Noise Location.

A trained and experienced mechanic can often tell from the noise made by an engine or machine whether everything is working as it should, and frequently any fault will produce a quite distinctive noise of its own, capable of identification by reason of volume and/or pitch.

It is in this latter respect that sound amplification can make a useful contribution to identification. A small 10 or 20 watt amplifier is used, and its output fed into what is termed a "filter" network. This network is an arrangement of inductance and capacity so chosen that it will offer a high impedance (sometimes called "dynamic resistance") to a pre-determined pitch, *i.e.*, frequency of sound.

If the capacity in the circuit should be made variable, then the sound frequency to which it offers maximum impedance will also vary, and in this way the relative sound intensities at varying frequencies can be measured. This method has been successfully adopted as part of the noise and efficiency tests on gear speed transformers.

Here, with the gears running at pre-determined speeds, noises due to pitch errors, shock loading of teeth, etc., are singled out, amplified, and graphically recorded. They can then be studied at leisure, and the alterations in tooth shape necessary to remove the cause of noise made with confidence.

With a constant amount of amplification, properly compensated for frequency, the difference in sound levels can be accurately obtained and the power level or loudness difference measured in decibels. The number of decibels by which any one power differs from another is given by the expression :—

N (decibels) $= 10 \log_{10} P_2/P_1$, where
P_1 = input power.
P_2 = output power.
P_2/P_1 = power ratio.

It will be noted that decibels give a power difference only, and to be of any use this difference must be expressed relative to some fixed level of power.

In acoustics the arbitrary zero pressure level is generally taken as 1 dyne/sq. cm., and the velocity zero 1 cm./sec.

The phon, the true measure of acoustic loudness, is expressed in the same manner as the decibel, and zero level of loudness, *i.e.*, 0 phons, corresponds to a pressure of ·0007 dynes/sq. cm. at 400 cycles/sec.

7. Anodic Treatment of Light Alloys.

The anodising of aluminium and other light alloys is an electronic-chemico process in which the material being treated is used as the anode for a current of uni-directional or alternating electricity passing through an electrolyte, *i.e.*, a liquid conductor of electricity.

This differs from the usual electro-plating process, in which metal is deposited on the material which is usually the cathode of the circuit. In anodising, the coating is obtained from the deposition of oxygen and the metal itself, and is in fact a tough coating of alumina.

The Aluminium Company of America has a patented "Drumilite" process which secures a very adherent dense coating of aluminium oxide, the constituents of the electrolyte being varied according to the type of coating required. The colours produced are very attractive, having a metallic lustre, which produces the effect of internal lighting, something like the flamboyant finishes lately used on bicycle frames.

Whilst the coating itself is of a hard, corundum-like quality, the colours are not quite light proof, thus making them more suitable for interior rather than exterior use. Greater light fastness can be obtained at the expense of colour quality by using mineral dyes. Aluminium coated in this manner is exceptionally resistant to corrosive influences, such as sea-water, etc., but is rather liable to surface cracks in forming operations.

It is possible to produce a coating that will allow of forming without undue cracking, but this type of finish is not so hard or so resistant to corrosion.

In anodising, the material must first be thoroughly degreased and washed, and it should be noted that alloys containing over 5% copper are rather difficult to anodise successfully, as are alloys high in silicon. After treatment, the material should be washed in first cold, then hot water, and well dried. The addition of a coat of paint and/or varnish will increase corrosion resistance, as the anodic coat is very absorbent.

TABLE II.

ELECTROLYTE.	TEMP. IN °C.	VOLTAGE	TIME IN MINUTES.	APPROXIMATE CURRENT DENSITY IN WATTS Per Sq. Ft.	A.C. OR D.C.	CATHODE	COLOUR OF FINISH.
3% Cromic acid in water.	40	Slowly from 0 to 40	First 15	200 to 250	D.C.	Soft Iron or Carbon.	Grey
		40	15th to 50th.				
		40 to 50	50th to 55th.				
		50	55th to 60th.				
Dilute Sulphuric Acid, Sp. gr. Approx. 1.220 with trace of glycerine.	20 to 22	Slowly to 3	First 5	280 to 300	D.C.	Soft Iron or Carbon	Clear and transparent.
			5th to 15th				
		3 slowly to 15	15th to 30th				
		15	30th to 35th				
		15 to 30	35th to 65th				
Oxalic acid with trace of Chromium salts.	20 to 30	Constant between 40-60	60	280 to 350	D.C.	Soft Iron or Carbon.	Golden
	20	Constant between 15-30		200 to 300	A.C.	Material is used for both electrodes	

Voice-Operated Mechanisms.

Voice-operated apparatus has not yet reached the same pitch of development as most other electronic devices, but is nevertheless in quite a useful stage. Its principles are quite simple—more simple, in fact, than many other forms of apparatus—but the difficulties in practical application are very numerous.

Basically, voice-control is a method whereby certain frequencies in the human voice are selected, amplified, and made to do certain fixed operations. For instance, the vowels A, E, I, O, U each have a distinct fundamental frequency, quite irrespective of the voice of the individual forming them.

Different "tones of voice" are due in the main to the presence of a varying amount of harmonics in each person's voice, and the fundamental frequency is not affected to any marked extent.

Thus it will be seen that if provision is made for "accepting" one particular frequency via a microphone, the resulting electric current is capable of amplification to a stage where it can be made to do useful work. This obviously has some considerable disadvantages, in that each time the chosen vowel occurred, the electro-mechanical sequence would be put into operation, perhaps with very untoward results. It is, however, simple to arrange that more than one vowel shall be necessary, and that they shall occur in a definite sequence, thus effectively precluding the risk of unintentional operation. The selection of frequencies would be done by a network of iron-cored coils and condensers, and the amplification by the usual valve amplifier.

Applications of the system are quite numerous, and one commercial passenger elevator has been running successfully for some time with its "floor call" done by speaking into a microphone the number of the floor on which one is standing, and then, when inside the elevator, the number of the floor one requires.

It only requires a course of intensive research to enable a large amount of operations at present requiring a certain amount of manual dexterity to be done by voice-controlled electronic apparatus.

APPENDIX I.

TIME CONSTANT.

"Time constant" is a term frequently used in electronic engineering technique, and is accepted as being a measure of the period required for a condenser to acquire a certain charge. Suppose a condenser to be connected in series with a resistance and a source of constant voltage. The condenser will charge up at a rate dependent upon, *inter alia*, the potential difference across its terminals, and when the condenser has no charge this voltage will be at its maximum. The flow of current (charging current) into the condenser will then be limited solely by the resistance. As the charge held by the condenser increases, the potential difference across its terminals will be smaller, and consequently the rate of flow of charging current will decrease.

Thus it will be seen that a condenser can theoretically never acquire a terminal voltage equal to the supply voltage, *i.e.*, it can neither be completely charged nor discharged.

When an effect varies in a manner dependent upon itself, any law expressing its relation will involve a constant termed *e*, this constant being frequently met in physics. The numerical value of this letter is approximately 2·7183 and it is used as the base of hyperbolic or natural logarithms.

By the use of this constant the law expressing the voltage across the terminals of the condenser in terms of capacity, supply voltage, and time is of the form :—

$$v = V\left(1 - \frac{1}{e^{t/CR}}\right) \qquad (1)$$

where v = condenser voltage.
V = supply voltage.
e = 2·7183.
t = time in seconds.
C = capacity in Farads.
R = resistance in ohms.
or, C = capacity in micro-Farads,
when R = resistance in megohms.

The symbol V is used to represent voltage, to avoid confusion with the symbol *e*.

If the time be made equal to C × R, then the equation becomes :

$$v = V\,(1 - 1/e), \qquad (2)$$

which is

$$v = 0{\cdot}63\ V \qquad (3)$$

Therefore, it can be stated that the condenser voltage will rise to 63% of its full amount in a time equal to C × R seconds. This is the "time constant" of a resistance-condenser network.

The same law applies to the discharge of a condenser through a resistance, the amount of discharge being proportionate to the amount of charge left in the condenser, that is :

$$v = \frac{V_1}{e^{t/CR}} \qquad (4)$$

where v = condenser voltage.
V_1 = initial voltage.
Other values as before.

So that in a time, $t = CR$ seconds, the condenser voltage will have fallen to 100 - 63 per cent. of its initial figure, that is, to 37%.

If t is equal to, or less than, 10% of CR, then the condenser voltage will fall 10% or a proportionate amount in time t, so that when t is small compared to CR, the discharge for that time is very nearly linear.

BIBLIOGRAPHY.

Title.	*Author.*	*Publisher.*
"Cathode Ray Tubes"	von Ardenne	Pitman.
"An Introduction to the Cathode Ray Oscillograph"	F. G. Spreadbury	Draughtsman Pub. Coy.
"The Low Voltage Cathode Ray Tube and Its Applications"	G. Parr	Chapman & Hall.
"Cathode Ray Oscillographs"	J. H. Reyner	Pitman.
"Electron Tubes in Industry"	K. Henny	McGraw-Hill.
"Thermionic Emission"	T. J. Jones	Methuen.
"Electron Optics"	C. M. Myres	Chapman & Hall.
"Industrial Radiography"	A. St John and H. R. Isenburger.	J. Wiley & Sons.
"Applied X-Rays"	G. C. Clarke	McGraw-Hill.
"Photo-Cells and Their Applications"	V. K. Zworykin and E. D. Wilson.	Chapman & Hall.
"Photo-Electric and Selenium Cells"	T. J. Fielding	Chapman & Hall.
"Electric Circuits and Wave Filters"	A. T. Starr	Pitman.
"High Frequency Heating for Plastics"	Br. Plastics and Mod. Plastics, November, 1943.	
"Electrical Technology"	Cotton	Pitman.
"Radio Receivers and Transmitters"	Amos & Kellaway	Chapman & Hall.
"Electro-plating and Anodising"		Newnes.
"Fluorescent Lighting"	A. D. S. Atkinson	Newnes.

List of A.E.S.D. Printed Pamphlets and Other Publications in Stock.

*The Craft of Tracing,	
* (6d to members, others, 1/-. Post Free).	
Lost Volumes from Cones,	W. R. Thomson
The Parallel Operation of Diesel-Alternator Sets,	G. H. Bradbury
Introduction to Jig and Tool Draughting,	A. Leigh
*Principles of Automatic Motor Control	B. Feldbauer
* (1/6 to members, 3/- others. Post Free).	
Pumping and Flooding of Ships,	E. W. Ansell
Power Station Auxiliaries,	T. H. Carr
Devices for the Prevention of Damage to Machinery,	A. Clarke
Notes on Some Modern Methods of Structural Analysis,	F. Simpson
Static Rectification,	F. G. Spreadbury
Magnetism in Industry and Science,	H. E. Hutter
Modern Screw Propeller Geometry,	A. W. Riddle
Brakes for Locomotives and Other Rail Units,	George W. McArd
Ward Leonard Control of Planer Type Machine Tools,	B. Feldbauer
Surface Condenser Design,	Robert B. Neilson
Reinforced Concrete,	J. McHardy Young
Dynamic Balancing,	A. Bell
Fluid Film Lubricated Bearing Practice,	G. S. Elfer
*Power Station Civil Engineering and Building Works,	T. H. Carr
* (1/6 to members, 3/- others. Post free)	
The Current Rating of Paper Insulated Cables,	C. C. Barnes
Treatise on Ventilation and the Design of Ductwork for Air Flow,	Thos. W. Beard
The Design of Structural Welded Details,	Frank H. Abrahams
The Recovery and Utilisation of Waste Heat,	J. A. Hagley
Machines for Dynamic Balancing,	Ralph M. Eggleston
An Introduction to the Construction of Nomographs,	William W. Calder
Foundations,	J. McHardy Young
An Introduction to the Cathode Ray Oscillograph,	F. G. Spreadbury
Panels and Panelling,	K E. Harper
Design of Concrete Sections,	W. Scott Wilson
Industrial Ventilation and Air Treatment,	M. R. Morton
Some Notes on the Stresses in Flat Rectangular Plates Under Pressure and The Design of Hopper and Suspended Type Bunkers,	George D. Mouat
Electricity Sub-Stations,	T. H. Carr
The Analysis of Braced Frames by the Method of Shear Coefficients,	F. H. Abrahams
Concrete Slab and Girder Floors,	W. Scott Wilson
Helical Gears for Marine Turbines,	Duncan Carmichael
An Elementary Introduction to Industrial Electronics,	Kenneth J. Field

All not otherwise marked are 1/- to members, 2/- others, post free.

List of A.E.S.D. Data Sheets.

1. Safe Load on Machine-Cut Spur Gears.
2. Deflection of Shafts and Beams } Connected.
3. Deflection of Shafts and Beams (Instruction Sheet)
4. Steam Radiation Heating Chart.
5. Horse-Power of Leather Belts, etc.
6. Automobile Brakes (Axle Brakes) } Connected.
7. Automobile Brakes (Transmission Brakes)
8. Capacities of Bucket Elevators.
9. Valley Angle Chart for Hoppers and Chutes.
10. Shafts up to 5½-in. diameter, subjected to Twisting and Combined Bending and Twisting,
11. Shafts, 5¾ to 26-inch diameter, subjected to Twisting and Combined Bending and Twisting.
12. Ship Derrick Booms.
13. Spiral Springs (Diameter of Rd. or Sq. Wire).
14. Spiral Springs (Compression).
15. Automobile Clutches (Cone Clutches).
16. ,, ,, (Plate Clutches).
17. Coil Friction for Belts, etc.
18. Internal Expanding Brakes. Self-Balancing Brake Shoes (Force Diagram) } Connected.
19. Internal Expanding Brakes. Angular Proportions for Self-Balancing
20. Referred Mean Pressure Cut-Off, etc.
21. Particulars for Balata Belt Drives.
22. ⅞″ Square Duralumin Tubes as Struts.
23. 1″ ,, ,, ,, ,,
24. ¾″ Sq. Steel Tubes as Struts 30 ton yield).
25. ⅞″ ,, ,, ,, (30 ton yield).
26. 1″ ,, ,, ,, (30 ton yield).
27. ¾″ ,, ,, ,, (40 ton yield).
28. ⅞″ ,, ,, ,, (40 ton yield).
29. 1″ ,, ,, ,, (40 ton yield).
30. Moments of Inertia of Built-up Sections (Tables) } Connected.
31. Moments of Inertia of Built-up Sections (Instructions and Examples)
32. Reinforced Concrete Slabs (Line Chart) } Connected.
33. Reinforced Concrete Slabs (Instructions and Examples)
34. Capacity and Speed Chart for Troughed Band Conveyors.
35. Screw Propeller Design (Sheet 1, Diameter Chart) } Connected
36. ,, ,, ,, (Sheet 2, Pitch Chart)
37. ,, ,, ,, (Sheet 3, Notes and Examples)
38. Open Coil Conical Springs.
39. Close Coil Conical Springs.
40. Trajectory Described by Belt Conveyors.
41. Metric Equivalents.
42. Useful Conversion Factors.
43. Torsion of Non-Circular Shafts.
44. Railway Vehicles on Curves.
45. Chart of R.S. Angle Purlins.
46. Coned Plate Development.
47. Solution of Triangles (Sheet 1, Right Angles).
48. Solution of Triangles (Sheet 2, Oblique Angles).
49. Relation between Length, Linear Movement and Angular Movement of Lever. (Diagram and Notes).
50. ,, ,, ,, ,, ,, ,, (Chart).

51. Helix Angle and Efficiency of Screws and Worms.
52. Approximate Radius of Gyration of Various Sections.
53. Helical Spring Graphs (Round Wire)
54. ,, ,, ,, (Round Wire) } Connected.
55. ,, ,, ,, (Square Wire)
56. Relative Values of Welds to Rivets.
57. Ratio of Length/Depth of Girders for Stiffness.
58. Graphs for Strength of Rectangular Flat Plates of Uniform Thickness.
59. Graphs for Deflections of Rectangular Flat Plates of Uniform Thickness
60. Moment of Resistance of Reinforced Concrete Beams.
61. Deflection of Leaf Spring.
62. Strength of Leaf Spring.
63. Chart showing Relationship of Various Hardness Tests.
64. Shaft Horse Power and Proportions of Worm Gears.
65. Ring with Uniform Internal Load (Tangential Strain)
66. Ring with Uniform Internal Load (Tangential Stress) } Connected.
67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub).
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain
70. ,, ,, ,, ,, Stress } Connected.
71. Ring with Uniform External Load, Tangential Strain
72. ,, ,, ,, ,, ,, Stress } Connected.
73. Viscosity Temperature Chart for Converting Commercial to Absolute Viscosities
74. Journal Friction on Bearings } Connected.
75. Ring Oil Bearings
76. Shearing and Bearing Values for High Tensile Structural Steel Shop Rivets, in accordance with B.S.S. No. 548/1934
77. Permissible Compressive Stresses for High Tensile Structural Steel, manufactured in accordance with B.S.S. 548/1934 } Connected.
78. Velocity of Flow in Pipes for a Given Delivery
79. Delivery of Water in Pipes for a Given Head } Connected.
80. Working Loads in Mild Steel Pillar Shafts.
81. Involute Toothed Gearing Chart.
82. Steam Pipe Design. Chart showing Flow of Steam through Pipes.
83. Variation of Suction Lift and Temperature for Centrifugal Pumps.
84. Nomograph for Uniformily Distributed Loads on British Standard Beams
85. ,, ,, ,, ,, ,,
86. ,, ,, ,, ,, ,, } Connected.
87. Notes on Beam Design and on Use of Data Sheets Nos. 84-5-6
88. ,, ,, ,, ,, ,,
89. Curve Relating Natural Frequency and Deflection
90. Vibration Transmissibility Curve for Elastic Suspension
91. Instructions and Examples in the Use of Data Sheets No. 89 and 90 } Connected.
92. Pressure on Sides of Bunker.

93-4-5-6-7. Rolled Steel Sections.
98-99-100. Boiler Safety Valves.

(Data Sheets are 2d to members, 4d to others, post free).

Orders for Pamphlets and Data Sheets to be sent to the Editor, *The Draughtsman*, cheques and orders being crossed "Draughtsman Publishing Co., Ltd."